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Study on the pulsed flow control on radiant cooling and heating systems in part load

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Abstract

In this paper, we propose a pulsed flow control of the radiant system with a fixed on-time to replace the storage water in pipes and a variable off-time to regulate the capacity. We developed a three-dimension numerical model to simulate the performance of the radiant heating and cooling system in the pulsed flow control method. Through numerical simulation on radiant systems with various thermal masses, the average supply and return water temperature difference and surface temperature non-uniformity were compared between the pulsed flow control and the variable flow rate control. The results demonstrate that the pulsed flow control achieves a comparable supply and return water temperature difference and pump energy consumption to the variable flow rate control. However, the pulsed flow control method saves the initial cost by substituting proportional valves by two-way position valves and has a higher controllability in part load. Furthermore, the pulsed flow control yields a smaller surface temperature non-uniformity than variable flow rate control, which is beneficial to reduce the condensation risk in cooling condition.

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Keywords: Radiant slab system; Pulsed flow control method; Laboratory experiment; 3D numerical model; Energy performance; Sensitivity analysis

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1. Introduction

Nowadays building energy consumption is still increasing with the development of economy and society. Further 30%-60% of the total building energy is consumed by air-conditioning system which is responsible for satisfying the heating and cooling requirements [1]. Radiant cooling and heating systems, relying on pipes to distribute cooled/hot water throughout a building, have gained appreciable interest and success for a variety of applications in new buildings and renovations [2]. Radiant cooling and heating systems have been proven to be more energy efficient than conventional air conditioning systems [3]. Besides, they are the important terminals for the application of high temperature cooling and low temperature heating.

For a centralized radiant cooling system in a building, the supply water temperature is always the same for different terminal units in order to meet the heating/cooling load of the worst room. Various control methods have been developed to regulate the heating/cooling capacity of the radiant systems. They can be classified into variable temperature control and variable flow rate control method. The variable temperature control method utilizes a proportional valve to mix supply and return water to obtain a required water temperature for the radiant systems. However, the variable temperature control method causes blending loss and decrease of the supply and return water temperature difference [4]. The variable flow rate control utilizes a proportion valve to control the water flow rate to regulating the capacity. However, the water velocity is not sensitive to the capacity of the radiant systems [5]. Therefore, a novel control method that achieves a high supply and return water temperature difference, low transport energy consumption and high controllability is still required.

In this study, we proposed a pulsed flow control method for radiant cooling and heating systems. The pulsed flow control method uses a two-way position valve and has a constant on-time duration and a variable off-time duration to regulating the capacity. We evaluated the performance of pulsed flow control method in part load and compared it with the conventional variable flow rate control.

Nomenclature

a	Thermal diffusivity (m^2/s)
c_p	Specific heat ($J/(kg \cdot K)$)
h_w	Convective heat transfer coefficient in pipes ($W/(m^2 \cdot K)$)
h_f	Heat transfer coefficient of convection and longwave radiation ($W/(m^2 \cdot K)$)
L_1	Pipe spacing (m)
P	Period in PFM (s)
q_s	Floor surface heat flux (W/m^2)
q_{max}	Maximum heat flux (W/m^2)
T	Temperature (°C)
$T_{f,min}$	Lowest floor surface temperature (°C)
T_s	Supply water temperature (°C)
$T_{w,i}$	Chilled water temperature in the *i*th water pipe (°C)
T_z	Indoor operative temperature (°C)
v_w	Water velocity in pipes (m/s)
θ_w	Non-dimensional supply and return water temperature difference
φ	Non-dimensional cooling capacity
$\theta_{f,min}$	Non-dimensional lowest floor surface temperature
τ	Time (s)
λ	Thermal conductivity ($W/(m \cdot K)$)
ρ	Density (kg/m^3)